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Novel aspects of holographic technologies and applications based on new stationary and dynamic holographic media

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14. ABSTRACT

This report results from a contract tasking of the Ioffe Institute as follows: Historically Russian holographic research laboratories developed many unique materials having no analogs in other countries. This effort leverages that expertise and investigates two aspects related to correction of distortion of laser communications signals:

1. Development of the technique for compensation of atmospheric distortions in laser communication systems by means of dynamic holograms. We expect that depending upon the chosen holographic medium the following operational characteristics are attainable: Duration of a write/read/erase cycle - 1.0 msecond; Quality of correction - 80%; Improvement of the signal to noise ratio – 90%. The device will be automatic, real-time and reliable.
2. Development of a new holographic material based on self-developing dichromated colloids, for recording of stationary volume holograms. This task will include measurement of the optical effects caused by photoinduced structural changes and hopes to achieve a resolution of up to 5000 l/mm and sensitivity down to 100 mJ/cm2.

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Project goals

The following are the two major subtasks of the proposed project:

1. Development of the technique for compensation of distortions in laser beam wave front induced by inhomogeneous media, by means of dynamic holograms.
2. Development of a new holographic material on the base of dichromated colloids, for recording of stationary volume holograms

CONTENTS

1. Task 1.

1.1. Introduction

When an optical information is transmitted through the atmosphere, one of the most crucial factors decreasing the quality of transmittance, are optical disturbances in the atmosphere, causing the broadening of spatial frequency spectrum of the light beam, that can cause losses of the transmitted information. This arises a problem of compensation of these distortions or separation of undistorted beam, carrying the information. To resolve this problem different linear and nonlinear methods of correction are being developed for many years.

In linear adaptive optical systems such compensation is carried out by means of a large amount of discrete actuators that deform an adaptive mirror in a specific way. Such systems were under development for a long time and are being applied now in Earth based observatories. At the same time the drawbacks of such systems that limit their usability in some cases became clear. Among those are: high weight, huge amount of mechanical parts which diminish the reliability of the whole system, a limited dynamic range, a limited range of corrected distortions, a complexity of information transfer and mirror guidance in real time, even when powerful computers are used. All that also leads to the high cost of such systems. An example of successful solution of the task are works of Fugate [1] on the compensation of atmospheric distortions with the corrector, formed during the process of observation of a natural or artificial star, located behind the atmospheric layer, which can be considered as a point source of subdiffraction size.

Gabor in 1949 suggested to use his method of wavefront recording (holography) for correction of aberrations in a microscope [2]. A little later his ideas were further developed by Leith and Upatnieks [3] and Kogelnik [4]. In their works it was demonstrated that random distortions can be corrected if the same phase inhomogeneities are introduced in the beam recording the hologram and in the beam reconstructing it. In 1966 Goodman and colleagues [5] suggested to transport both the object and reference beams, recording the hologram, through the distorting medium (Figure 1). In this case on the stage of reconstruction the hologram, being illuminated by a homocentric beam, reconstructs an undistorted object wavefront.

???. 1. Goodman's schematic on the correction of atmospheric distortions.

The above mentioned correction methods were further developed by the authors in their later works [6-9]. Thus, the holographic method introduced by Gabor allows to correct distortions in optical signals, among them to correct optical distortions induced by atmosphere.

At present time nonlinear methods of correction attract a lot of attention and are being developed very fast and for different applications. Clearly, these methods can be used for correction of both static and dynamic distortions of wavefronts.

The present research was aimed to consider nonlinear methods of correction for random and a priori unknown phase inhomogeneities similar to those induced by atmosphere, to analyze main requirements to the technology of holographic dynamic correction of an optical signal propagating through a disturbing medium, to analyze the existing holographic materials suitable for this task, to carry out modeling correction experiments in the laboratory conditions, as well as to formulate the tasks for future research on the problem of atmospheric correction in laser communication systems.

1.2. Dynamic holographic materials.

1.2.1. Main requirements to a holographic medium

In recent years there was a noticeable progress in development of different kinds of nonlinear holographic recording media. Among them in regard to the atmospheric correction it's necessary to mention photorefractive crystals, photochromic materials, photothermoplastics, as well as optically addressed spatial light modulators on the base of liquid crystals. The general problem with nonlinear optical media is that typically it is difficult to simultaneously have high sensitivity, high resolution, fast operation, and high diffraction efficiency.

The main requirements to a holographic material to be applicable for operation as a dynamic holographic wavefront corrector in laser communication systems are as follows:

- ***response time***. So far as the typical frequency of atmospheric variations is not higher than 200 Hz, that means that in a time scale a holographic medium has to perform the complete write-read-erase cycle within the millisecond range. The response time is also connected with the requirement on the medium ***sensitivity*** to the recording light which has to be relatively high for such short operation times.
- ***diffraction efficiency.*** Obviously, as high diffraction efficiency as possible is desired to minimize energy losses in the output signal beam.
- ***losses.*** For the same reason it is worth to minimize losses for scattering, absorption, reflection etc.
- ***spectral range***. The operation spectral range of the material must provide effective recording of the hologram and its non-destructive read-out. Usually laser communication systems work in near IR spectral range, at the wavelengths of 0.85, 1.06 and 1.5 μm. So there are two opportunities, either a hologram is recorded and read-out by the same laser wavelength in IR, or it is recorded by a different, beacon laser light (for example, visible) and reconstructed by the IR light. Both ways have advantages and disadvantages. In the first case it's very difficult to achieve the non-destructive read-out. In the second case the difference in wavelengths can be a source of additional unwanted aberrations in the resulting beam.

At present time the two classes of dynamic media used for information recording, namely, photorefractive crystals and liquid crystals, possess high optical sensitivity, relatively high diffraction efficiency and fast response, sufficient to correct optical signal propagating through an inhomogeneous medium.

1.2.2. Photorefraction. Photorefractive crystals

There are many different nonlinear effects described in literature that can be used to create a recording medium for dynamic holography or wavefront reversal (WFR) on the base

of four-wave mixing (4WM). However the most promising is the nonlinearity provided by the photorefractive effect, which was used in different applications for many years.

Photorefraction is the formation of a spatial charge distribution under the nonuniform light distribution, which changes the refractive index of the medium due to the electrooptical effect. Volume phase holograms can be recorded in photorefractive crystals, that allows then to perform the energy exchange between beams on the formed diffraction grating.

Thus, the recording of dynamic gratings in photorefractive crystals occurs as a result of the following processes:

- formation of the distribution of free carriers corresponding to the recording light distribution in a crystal (electrons in the conductivity zone, holes in the valence zone);
- transportation of carriers along the crystal due to diffusion and external and internal electric fields;
- capture of carriers by traps and formation of the spatial charge grating;
- refractive index modulation by the field of spatial charge with the formation of the dynamic diffraction grating.

For the realization of photorefractive effect deep local levels in a forbidden zone of a crystal are necessary, which can change their charge condition under the action of light with a corresponding wavelength. For this purpose special constituents that are able to capture a charge, are added into photorefractive crystals.

The advantages of photorefractive crystals are: high sensitivity, high spatial frequency (hundreds of lines/mm), and possibility to record volume holograms due to the thickness of the materials, which allows to achieve high diffraction efficiency. It is worth noting also that holograms can be erased by applying the external electric field or by illuminating them by a laser pulse of a specific wavelength. The main disadvantage is the relatively slow process of grating formation and erase, which is governed mainly by the speed of diffusion process. However, the frequencies of the write-erase cycles of at least 100Hz are achieved.

High efficiency volume phase holograms can be recorded in a variety of transparent electro-optic crystals. Examples are $LiNbO_3$, $LiTaO_3$, $BaTiO_3$, BSO, KTN etc., as well as semiconductor crystals with metastable doping centers, which operate in general faster than photorefractive crystals. The attractive features of the photorefractive crystals are high resolution and high diffraction efficiency. The following table presents some of existing photorefractive crystals with their parameters.

Medium	Spectral range	Sensitivity, J/cm^2	Diffraction efficiency, %	Time of response, down to, s	Source
$LiNbO_3$:Fe	Blue-green	1-0.1	100	100	[10]
$BaTiO_3$	Visible	10^{-2}	80	0.1-1	[10]
$Bi_{12}SiO_{20}$	Blue-green	$2 \cdot 10^{-3}$	10	10^{-2}	[10]
InP:Fe	IR	10^{-5}	0.1	10^{-4}	[10]
GaAs:Cr	IR	10^{-4}	1	$2 \cdot 10^{-5}$	[10]
CdTe:V	IR	-	-	$8 \cdot 10^{-3}$	[11]
GaP	IR	-	-	$5 \cdot 10^{-3}$	[12]
$KnbO_3:Rb^+$	Visible		3	$7 \cdot 10^{-4}$	[13]
$KNbO_3$	UV			$5 \cdot 10^{-6}$	[14]

1.2.3. Optically addressed SLMs on the base of liquid crystals

Spatial light modulators based on liquid crystals (LC SLMs) are under development for relatively long time and at present time there are many different kinds of these devices with a wide variety of photosensitive layer materials (e.g., chalcogenide, zinc selenide, α-CdTe, α-Si:H, polyimide etc.), that allows to choose most optimal characteristics for each particular application from a wide range of available choices.

The best effort parameters of such devices of different kinds achieved up to now can be summarized as follows:

- Minimal write-read-erase cycle - less than 1 ms.
- Spatial resolution - hundreds of lines per mm.
- Diameter - up to 50mm
- Sensitivity to the recording light - less than 1 $\mu J/cm^2$
- Diffraction efficiency - approaches the theoretical limit for thin holograms with sinusoidal structure, 33%. Higher diffraction efficiencies, up to 60%, were reported for gratings with the trapezoid shape of line.

At present time the research is carried out to combine all these promising features in one SLM ([e.g., 15, 16]).

The following table presents parameters of some particular LC SLMs:

LC SLM type	Switch-on/ Switch-off cycle time, ms	Sensitivity	Resolution, l/mm	Diffraction efficiency, %	Source
Commercially available ferroelectric, nematic	<1 30	40 $\mu W/cm^2$	30	Up to 40% Up to 34%	
Deformed-helix ferroelectric	0.6			35	[15]
Dye doped polyimide	~100	$5 \cdot 10^{-6}$ J/cm^2	200	17	[17]
Fullerene doped polyimide	~100	$(5\text{-}20) \cdot 10^{-7}$ J/cm^2	200	8	[18]

The mostly developed at present time are SLMs with the nematic liquid crystals. However, their speed may not be sufficient for the laser communications application. Ferroelectric liquid crystal SLMs perform much faster than nematic-based ones, and their speed approaches the required magnitude for a holographic corrector. The choice of a particular SLM for an automatic laser signal correction is to be based on the analysis and optimization of a combination of all the other critical parameters.

1.2.4. Other potential candidate materials

So far no one of the existing usual holographic dynamic media fulfills completely all the requirements to the compensating system under development, there are two general ways to find the optimal solution to this problem. The first one is to try to make small improvements of the parameters and optimize everything to approach the required values as closer as possible. And the second way is to turn the attention to less common materials. Among these unusual media there are some new ones, such as fullerene containing materials, and there are rather “old” ones, which were developed several decades ago and then attracted less interest of researches (such as metal vapors).

An attractive feature of fullerene containing materials is a speed of nonlinearity generation. In some cases ([19]) it can be of the order of picoseconds. In other materials it slows down to nano- or milliseconds. The negatives are a relatively low sensitivity and resolution. However, this class of materials is not well developed yet and research work is carried out in many groups all over the world. Another class of media, which should be mentioned, are atomic media with resonance absorption – the metal vapors. These media are also very fast, they work in the nano- to microsecond range, and in principle allow an unlimited number of write-read-erase cycles. Another attractive feature of these media is rather high sensitivity ($\sim 10^{-9}$ J/cm^2) ([20]). However, the complexity of technical arrangement keeps these media far away from practical applications.

1.3. Model experiments

1.3.1. Photorefractive WFR-corrector.

In the framework of the current research the demonstration experiments were carried out showing the possibility to compensate dynamic phase distortions using both the WFR in the 4WM schematic, and with the dynamic holographic corrector. The model distortions were introduced by means of the vibrating mirror placed in the object beam path. The photorefractive crystals BSO ($Bi_{12}SiO_{20}$) and BTO ($Bi_{12}TiO_{20}$) were used to record holograms. The hologram reconstruction was carried out by both the beam of the same wavelength and by the beam of a different wavelength.

Figure 2 presents the schematic of the experiment on the compensation of phase distortions via WFR method. It is well known that if a hologram is recorded by two beams I_R and I_S and is reconstructed by a beam I_P conjugated to I_R, it gives as a result a diffracted beam I_{PC}, conjugated to the beam I_S. When phase distortions change in time, the nonlinear medium in which the hologram is recorded, should be able to follow these distortions, so that for each new realization of the signal wave front a corresponding diffraction grating would be recorded. In our experiments we used the photorefractive crystal BSO ($Bi_{12}SiO_{20}$). The hologram recording time, τ_{sc}, in photorefractive crystals is proportional to the time of Maxwell relaxation, $\tau_M=\varepsilon\varepsilon_0/\sigma$, where σ is photoconductivity. That means that the higher the photoconductivity is, the lower is τ_M, and, respectively, τ_{sc}. The BSO crystal has the highest photoconductivity in the green range of spectrum. The estimations showed that the characteristic time for the write-erase cycle of a grating in BSO at the recording light wavelength of 530 nm and intensity of 100 mW is about 5 ms. Thus, this crystal can be applied for correction of dynamic distortions with the frequencies up to 200 Hz.

The scheme of experimental set-up is presented in Figure 2. A beam from Nd:YAG laser (L1) with the wavelength λ=530 nm was splitted into two beams I_R and I_S, used to record the hologram in the BSO crystal. Phase distortions were introduced into the signal beam (I_S) by harmonic vibrations of the mirror VM. The spatial frequency of the recorded grating was equal to 300 l/mm. To enhance the diffraction efficiency the drift mechanism of recording was used, provided by a constant external field (E_0=10 KV/cm) applied to the crystal.

To reconstruct the hologram the beam I_P either from the same laser, or from He-Ne laser (λ=632.8 nm, 20 mW) was used, which was directed onto the crystal in a way to fulfill the Bragg diffraction conditions. The diffraction of the beam I_P on the grating resulted in generation of a beam I_{PC} conjugated to I_S. A Michelson interferometer (BS3 and M5)

provided an interference of the beams I_{PC} and I_N (a beam with the constant phase and amplitude). The resulting distribution in this interference pattern (having the spatial frequency Λ^{-1}=0.5 l/mm) was analyzed by the photodiode D with a slit S. Obviously when the compensation is not achieved, interference pattern would move, oscillating on the slit and causing the amplitude modulation of light arriving on the photodiode.

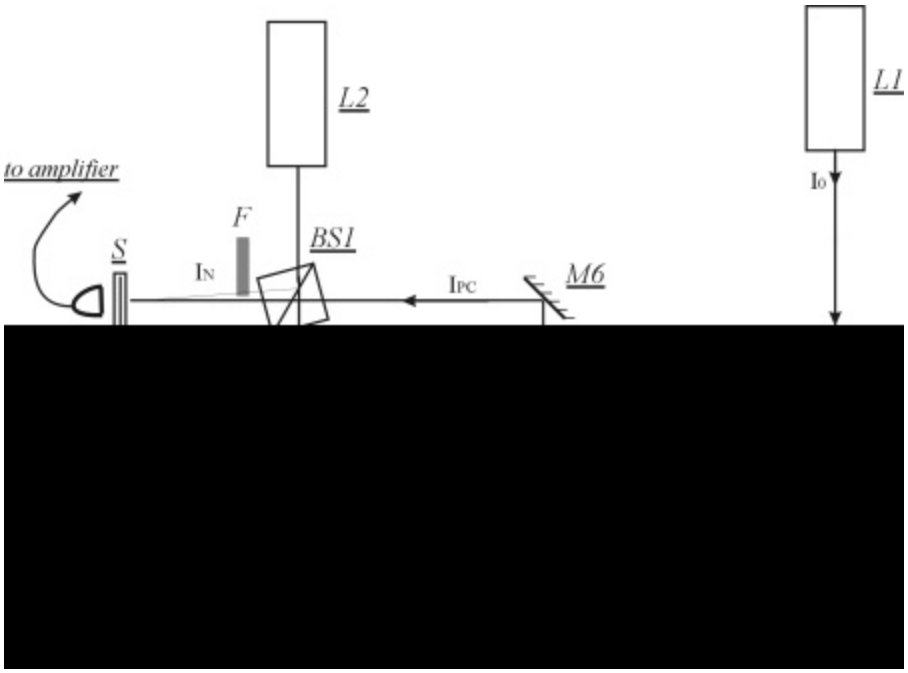


Figure 2. Experimental arrangement. L1 – Nd:YAG laser; L2 – He-Ne laser; BS1, BS2, BS3 – beamsplitters; M1, M2, M3, M4, M5, M6 – mirrors; VM – vibrating mirror, F – filter, S – slit, D – photodiode, BSO – crystal.

A low frequency phase modulation of the signal beam was carried out via vibrations of the mirror VM. This phase modulation was making the interference pattern to move on the crystal surface, oscillating at some mean position. The grating recorded in the crystal was following these movements up to a specific frequency magnitude corresponding to the material response characteristics. When the oscillating frequency exceeds this critical magnitude, the reversal quality becomes lower, because the grating "remembers" previous realizations of the signal beam wave front. This finally leads to only a partial correction of optical distortions.

Different methods can be used to measure the dynamic properties of the holographic corrector. We have chosen the method in which an analysis was made on the interference of the reversed wave passed through the aberrating element on the way back, with a reference wave which is a part of the reconstructing wave. Thus, in experiments a signal of interference of the I_{PC} and I_N beams was recorded (see Figure 3). The dependence presented in the Figure 3 has a constant section in the beginning, until the characteristic frequency, and after that rises up. The phase compensation thus is carried out up to the frequency corresponding to the time of grating recording.

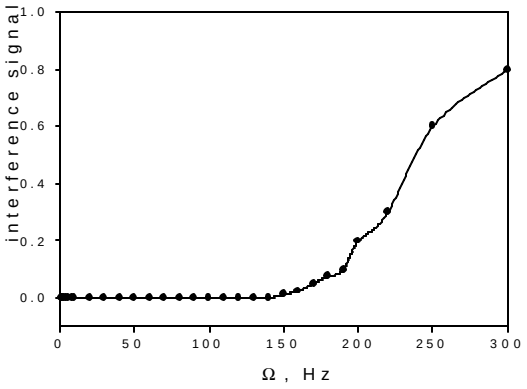


Figure 3. Interference signal of the beams I_{PC} and I_N as a function of phase modulation frequency.

1.3.2. Photorefractive holographic corrector.

The experimental setup for studies of compensation for dynamic phase distortions by means of a holographic corrector is shown in Figure 4. To record a hologram the laser beam was directed into the Mach-Zander interferometer consisting of the beamsplitter BS1 and mirrors M1, M2, M3. A phase aberrator A was placed into one path of the interferometer. The aberrator was harmonically oscillating in a direction perpendicular to the beam I_S, introducing dynamic distortions into the signal beam. The beams coming out of the interferometer, I_R with the plane front, and I_S with a distorted front, were interfering in the volume of the crystal $Bi_{12}TiO_{20}$ and were recording the volume phase hologram. To increase the diffraction efficiency of the hologram the drift mechanism of recording was used, and the BTO sample was made in so called anisotropic geometry, due to which the polarization of diffracted beam is perpendicular to that of the initial beam, that allowed to separate the transmitted and diffracted beams. As a result of the beam I_S diffraction on the hologram a beam with undistorted wave front was obtained. Obviously, in the case of dynamic aberrations, the undistorted wave will be reconstructed only when the characteristic time of aberration variation is longer than the hologram write-erase cycle. In our case this time was about 200 ms.

In experiments the diffracted beam selected by the polarizer P interfered with the plane beam I_0. The ineterference pattern was observed on the screen E. Starting from the frequencies of aberrator vibrations higher than 5 Hz (that corresponds to the recording time of 200 ms) the intereference pattern was distorted, while at lower frequencies no distortions were observed.

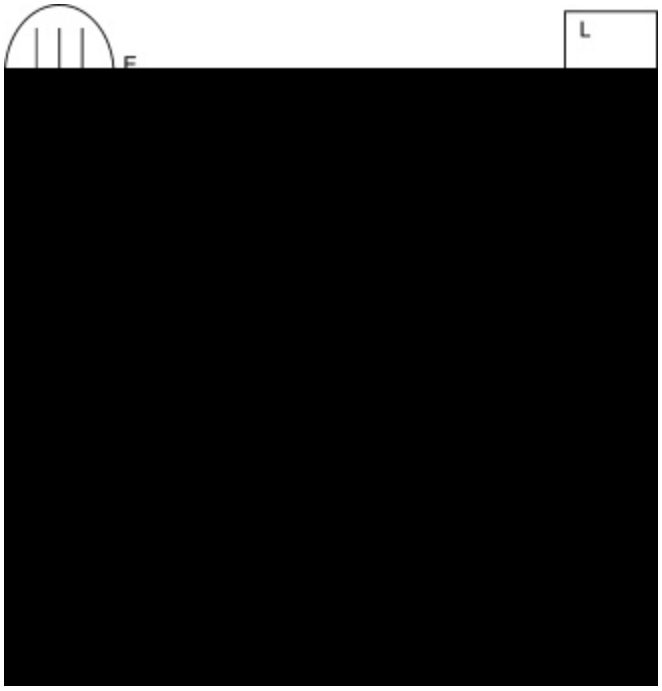


Figure 4. Experimental setup for compensation of dynamic phase aberrations by a holographic corrector. L – He-Ne laser; M1, M2, M3, M4 – mirrors; BS1, BS2, BS3 – beamsplitters; P – polarizers; S – BTO crystal, E – screen.

1.4. On the possibility of optical information transportation onto a moving object

In some cases the information has to be transferred onto a moving object located behind the disturbing layer (atmosphere). Such a situation is realized, for instance, at Earth-satellite links. To increase the link efficiency it's necessary to correct distortions induced by the atmosphere. However, the schematics described above can not be used because of the satellite movement. During the time required to transmit the signal from the satellite to the Earth and back, satellite moves to some distance. And the Earth surface also changes its position. In this case the light beam should be directed not exactly backwards, but on another path, inclined at some angle j. However, on this new path the optical inhomogeneities of the atmosphere are slightly different than those on the first path. In this case the WFR effect does not seem to give perfect results. A rather expensive solution would be a positioning of a beacon close to the satellite, which would also fly on the orbit. A combination of two nonlinear elements, namely, a dynamic hologram and a WFR mirror can give a cheaper solution. The technology works as follows. An information on the atmospheric distortions (in a sufficiently high angle of vision) is recorded in the volume hologram. Then this hologram is reconstructed in a new pre-calculated direction, which differs in a required angle j. Then the wave front reversal of this artificial signal beam is carried out by means of WFR mirror, and the resulting beam goes by the hologram and is directed onto the new position of the satellite. This beam will compensate atmospheric distortions if they didn't change considerably during the operation described.

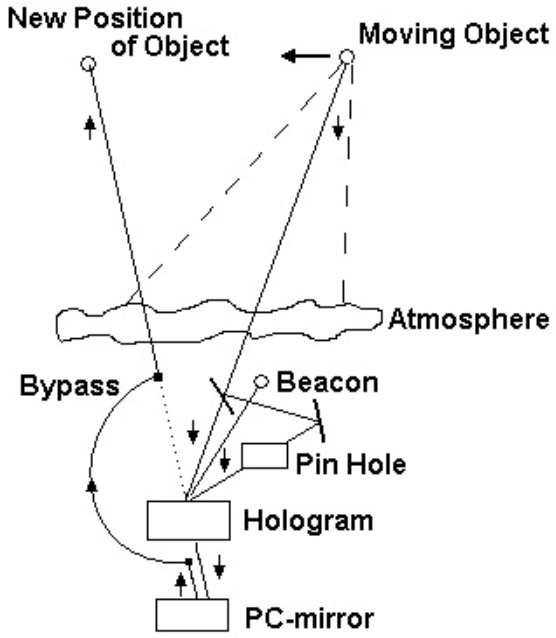


Figure 5. Application of the dynamic hologram and WFR mirror for compensation of distortions on a slightly changed atmospheric path.

An application of a WFR mirror on the base of degenerated 4WM can probably allow to combine the hologram and WFR mirror in one element and to avoid the additional radiation reconstructing the hologram from a direction corresponding to a new object position. However, in this case allowances should be made to a change of the object location.

1.5. Holographic spectral filters

The rapidly developing area of communications, both fiber and wireless, has a strong demand in spectral filters operating in near IR range. These filters are required to cut all the unwanted background radiation and diffract the useful part of incoming radiation carrying the signal.

The two major properties of volume holograms: high diffraction efficiency (close to 100%) combined with high spectral selectivity (depending upon the hologram thickness) make them rather promising for creating holographic spectral filters for various applications. The attractive feature of holograms is the possibility to widely vary the final parameters of a filter by choosing the appropriate recording material and recording geometry.

Holographic spectral filters available on the market nowadays are recorded in standard holographic materials (such as DCG or DuPont photopolymers), with the layer thickness of 10-20 micrometers, that allows to obtain elements with the bandwidth of selectivity contour down to a few dozens of nanometers. The usage of thicker layers makes it possible to achieve much higher selectivities, however, the more developed now is the range of selectivities below 1 nm, that is governed by the existence of thick holographic materials allowing to record holographic gratings of millimeter thickness, and possessing no shrinkage. The first extremely selective holographic spectral filter with the selectivity 1.5 Å and diffraction efficiency 40% was recorded in the sample of photopolymer Reoxan 1 mm thick ([21]). In ([22-24]) filters with the selectivity from 1 down to 0.5 Å and diffraction efficiency over 90% were recorded in photopolymer with diffusive amplification. These

filters were optimized for operation at different wavelengths in visible and near IR spectral range. There were also reports on narrowband spectral filters recorded in photorefractive crystals, $LiNbO_3$ in particular ([25]), as well as tunable narowband filters in photorefractive crystals ([26]).

Until recently it was rather difficult to obtain holographic spectral filters with the selectivity of the order of nanometers, that resulted from the lack of recording materials with the thickness from 50 up to 100-200 micrometers. One of the rare possibilities is DCG, which allows to record filters with such a selectivity and optical density up to 6 ([27]), but it is rather difficult in processing and succeeding usage. The new holographic photopolymer from DuPont, 50 micrometers thick, is a good candidate to successfuly compete with DCG to fill in this gap and to obtain filters with the desired selectivity.

The theoretical analysis shows that, in general, reflection holograms are more suitable for recording highly selective spectral filters. First of all, reflection holograms are more spectrally selective than transmission ones with corresponding parameters. That allows to achieve the desired spectral selectivity using more thin holograms. Besides that, reflection holograms are much less angular selective than transmission ones, that makes them more convenient in operation. And finally, in the reflection configuration, inhomogeneities in depth of both the material itself and of the recorded holographic structure have less influence on the resulting image quality.

The other principal difference is associated with the required exposure in order to achieve the maximal diffraction efficiency. For transmission holograms it is associated with the product of the hologram thickness T and its amplitude of refractive index modulation Δn. The definite combination of these parameters allows to achieve the maximal efficiency (up to 100%). For reflective holograms the situation is different. The enhancement of these parameters, T and Δn, leads to an asymptotic approach of diffraction efficiency to its maximum (theoretically 100%). And finally, the angular selectivity of reflection holograms is lower than that of transmission ones with corresponding parameters. That is why, in general, if the particular application permits, reflection holographic filters are preferred over transmission ones.

In the experiments we used two 50-micrometers thick new films from DuPont that differed only in maximal refractive index modulation amplitude: the first one had high $\Delta n = 0.065$, and the other one had low $\Delta n = 0.013$. Filters optimized for different wavelengths in visible and near infrared spectral range were recorded. The following results were obtained.

Filters optimized for operation at 532 nm were recorded with the maximal OD over 4 and FWHM of spectral selectivity contour of 16 nm in the material with high dynamic range. However, it is necessary to mention that the material exhibits a noticeable shrinkage. The other important aspect is the rise of light scattering after processing. For the high refractive index modulation material we observed an almost ten-fold increase of scattering. It is caused probably by the rise of dynamic noises, with sources of initial light scattering in surfaces, polymer matrix, photosensitive composition itself and in recording optics.

The initial diffraction efficiency of holograms after recording was of the order of 50-60%, then it raised up to about 90% after UV illumination and was enhanced to the final magnitudes after baking. However, we also observed that the recommended baking regime did not provide the complete fixing of holograms. While being stored even at the room temperature filters exhibit a noticeable shift of the diffraction maximum to shorter wavelengths. The maximal recorded shift was of the order of 25 nm. At the same time this shift was accompanied by a slight rise of diffraction efficiency, which is probably due to residual diffusion processes and after-polymerization of samples. We tried to extend the baking time up to 8-10 hours, and that allowed to completely eliminate these effects. The much longer baking however caused the decrease of overall hologram transmission.

In experiments we recorded filters optimized for near IR in both the films. In accordance with the theoretical results, the selectivity contour of the filter recorded in the material with lower dynamic range is much narrower than that in the material with higher dynamic range. On the contrary, the diffraction efficiency of the second one is higher than that of the first one. In Figure 6 the selectivity contour for a holographic filter recorded in the material with higher dynamic range is presented.

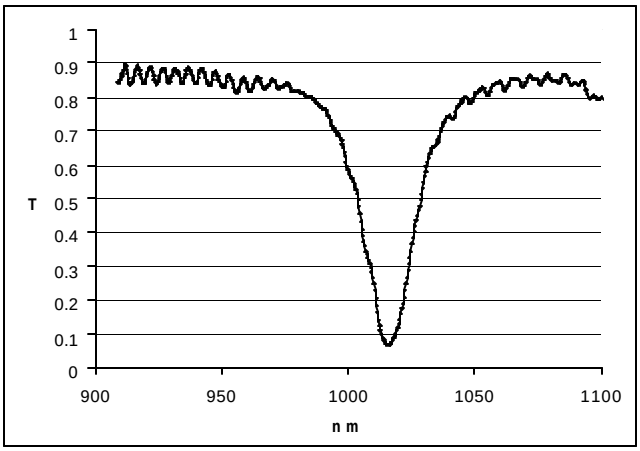


Figure 6. Experimental contour of spectral selectivity of a holographic filter recorded in the DuPont photopolymer with high dynamic range.

Thus, we demonstrated that the new photopolymer film from DuPont, 50 micrometers thick, can be successfully used for recording holographic spectral filters with selectivities from a couple of dozens of nanometers down to several nanometers. Such filters can be optimized for operation in both visible and near IR. The maximal optical density achieved for the notch configuration exceeded 4. It is worth noting however, that when recording such narrowband elements as spectral filters, allowances should be made to the observed material behavior, namely, wavelength shift caused by hologram processing, possible wavelength shift in the case of insufficient baking time, as well as the connection of spectral selectivity bandwidth with the grating strength.

1.6. Conclusions.

The reliable automatic compensation of disturbances induced in laser communication signals by the atmosphere could solve one of the most difficult problems in free space laser communication systems. The unique advantages given by holographic technique make it rather promising to develop a relatively simple and reliable module for correction of atmospheric distortions in such systems. One of the main problems though is to find an optimal medium for hologram recording, allowing sufficiently fast write-read-erase operation, high diffraction efficiency, high stability of characteristics and unlimited number of operation cycles. The analysis of different kinds of dynamic holographic recording media developed to the moment shows that in principle if choosing the most optimal material it is possible to approach the necessary requirements for application in such systems.

During the work on the project all the main tasks were fulfilled. Namely, the main requirements to the technology of dynamic correction of aberrations of an optical signal

transmitted through the inhomogeneous medium, were determined. An analysis of existing holographic materials suitable for recording of such holograms, has been made. A laboratory testing of the most promising materials (photorefractive crystals) has been made. The possible architectures of the correction module were developed, the model experimental evaluations of the proposed schematics were made. It has been mentioned that the combination of two nonlinear elements: the hologram and WFR mirror give some advantages to the technology.

2. Task 2

2.1. Introduction

In 1968, Shankoff [28] proposed to implement hologram recording using layers of dichromated gelatin (DG) and demonstrated the possibility to record highly efficient DG holograms through the stage of fast dehydration of a recording layer with propanol. Dichromated gelatin is a practically ideal phase holographic recording material, which makes it possible to approach the theoretical limiting value of the DE and to record more than 1000 superimposed holograms [29,30]. However, the low photosensitivity of *DG* photomaterials as compared with silver-halide photoemulsions and the low reproducibility of the results of recording with DG holograms restrict applications of DG media to predominantly the replicating and printing of holograms and diffraction optical elements. Analysis of the recently proposed methods of real-time hologram recording in *DG* layers in the regime of self-developing [31,32] demonstrates that the possibilities of chromated colloids are far from being exhausted.

Although extensive experimental material has been accumulated on this subject, much is still to be understood in the mechanism of optical-data recording in *DG* layers. Specifically, it is a common belief that holograms are recorded due to gelatin hardening under the action of light [33]. However, x-ray diffraction studies [34] have shown that the action of light increases the amorphization degree of gelatin rather than orders the crystalline structure. Strong modulation of the refractive index arising in DG was attributed to different processes, from a "helix- glomerule" intramolecular transition to purely mechanical cracking of a layer dried in isopropanol

An additional interest in improving DG media, which is the main subject of this report, is associated with the possibility to use DG materials to record "deep" holograms and selectograms [35], because such materials provide an opportunity to implement a truly three-dimensional rather than a film recording medium.

2.2. Cascade phase transitions in DG layers

In the present project we invoke the biophysical data [36,37] to consider the mechanism behind the recording of optical data in DG layers as a set of hierarchical interrelated phase transitions at various levels of gelatin structure, including the intramolecular, molecular, and supermolecular levels.

The main distinguishing feature of DG as a polymer is associated with the natural origin of gelatin. The native state of a gelatin macromolecule has a biohelix-like structure, which makes possible to prepare DG layers with an initially ordered (helical) molecular structure. In the process of development, a phase transition from the ordered (quasi-crystalline) state to a disordered (quasi-amorphous) state occurs under the action of light and water at all the levels of structure organization of a gelatin layer, which leads to large photoinduced changes in optical characteristics of a D*G* layer.

In other words, the synthesis of a DG layer before the recording process is accompanied by the appearance of stresses applied to "springs" representing the helical fragments of gelatin macromolecules. Then, the action of light plays the role of a trigger, which sets these springs free. The energy stored in these springs induces a cascade of phase changes in the state of a gelatin layer. These phase changes, in their turn, give rise to variations in the macroscopic characteristics of a recording medium.

Based on the concept of cascade phase transitions developed in this report, we propose methods for synthesizing DG layers with a required structure of the gelatin layer.

2.3. Levels of structure organization of gelatin layers

Gelatin is a highly asymmetric linear polypeptide polymer of protein nature. The molecular mass of gelatin macromolecules ranges from 40 000 to 1000 000 [38]. Similar to all proteins, gelatin is a high-molecular compound characterized by its ability to form various hypomolecular structures [36].

There are several basic levels in the structure organization of proteins (Fig. 7). The primary structure is determined by the composition and the sequence of amino acid radicals in a macromolecule of the polypeptide chain. The secondary structure is determined by the configuration and relative spatial arrangement of protein macromolecules, which have the shape of helixes, folds, or glomerules. The hypersecondary structure is determined by the aggregation of secondary-structure elements into a single macromolecule, which is manifested, in particular, as the phase state of the globular nucleus. The domain structure is determined by external parameters (the thickness of a layer, the degree of adhesion of the layer to a substrate, etc.) responsible for the formation of separate and relatively weakly bonded globular segments of a macromolecule. The ternary structure is determined by the conformation of protein helixes in the form of fibrils or globules. The quaternary structure is determined by die aggregation of protein fibrils and globules and. similar to the domain structure, is highly sensitive to external conditions (the conformation of a collagen-like triple hyperhelix is the limiting case of the quaternary structure for gelatin macromolecules) [35]. Distinguishing between the levels of structure organization of macromolecules, we assume that interactions of different types have distinct boundaries, and nonadjacent elements in the molecular chain or elements of different levels do not interact with each other.

Collagen - a family of natural polymers of protein nature - is a primary aggregate of gelatin macromolecules in living organisms, which provides the starling material for the formation of gelatin. The secondary structure of collagen has a shape of a left-handed hyperhelix consisting of three helical gelatin macromolecules [36]. The chemical composition and physical and mechanical properties of gelatin strongly depend on the prehistory and the ways of transformation of collagen into gelatin [38].

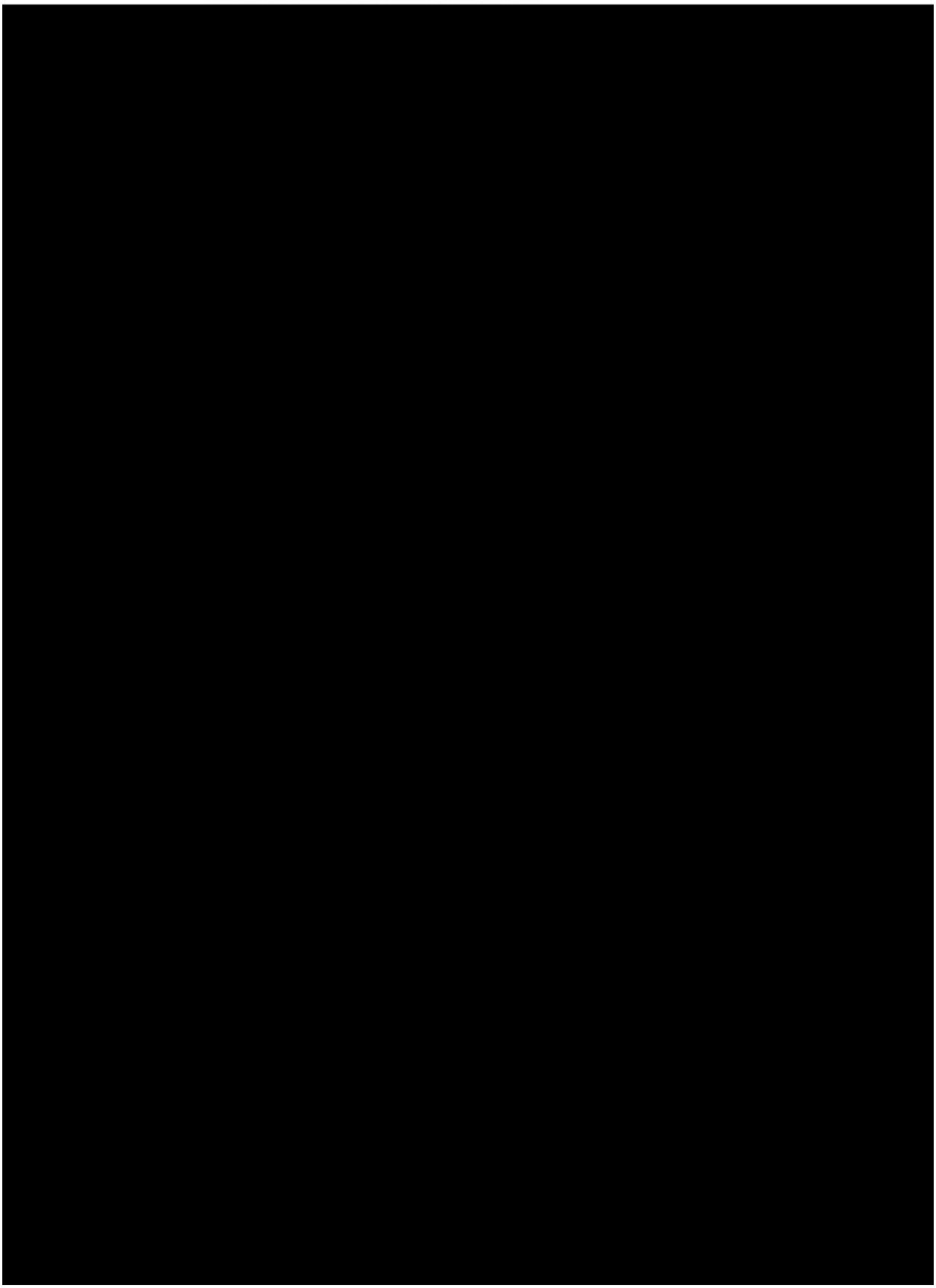


Fig. 7. Generalized diagram of structure organization levels and phase-structure transformations in gelatin systems.

2.3.1. Secondary structures of gelatin

Destruction of a triple helix of collagen is accompanied by the formation of single polypeptide chain macromolecules. In certain cases, monomer (α-component), dimer (β-component), and trimer (γ-component) fractions may also arise [38]. Monomolecular α-gelatin with a molecular mass of 40 000-100 000 possesses the best properties [38]. To estimate the quality of gelatin in the synthesis of DG layers, one can employ the viscosity coefficient of aqueous solution of gelatin [39].

The secondary structure is usually considered as consisting of a glomerule, α-helix, β-fold, and reverse points (Fig. 8). On the average, protein molecules contain 35% of α-helixes, 15% of β-folds, 25% of glomerules, and 25% of reverse points [36]. The α-helix-glomerule phase transition at the level of the secondary structure occurs within the temperature range of 20-25°C.

Chromium ions introduced into a gelatin layer at the stage of preparation of DG films are localized with the maximum probability near glomerate segments of macromolecules and near reverse points.

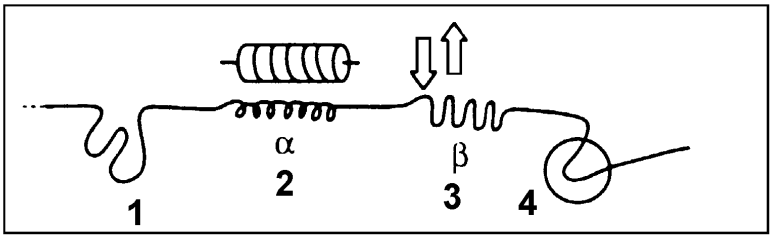


Fig.8. Secondary structures of the crest of a polypeptide macromolecule: (1) glomerula, (2) a-helix and its notation, (3) b-fold and its notation, and (4) reverse point.

2.3.2. Hypersecondary and domain structures of gelatin

The necessity to separate the hypersecondary and domain levels of structure organization of protein macromolecules is associated with the description of the dynamics of coagulation of macromolecules into a globular state [36,37]. The dynamics of coagulation or assembling (packing) of secondary structures can be interpreted as the motion of separate segments of a macromolecule. The introduction of the domain level for the description of the structure of a macromolecule is dictated by the necessity to take into account external parameters, including adhesion to a substrate [37]. From the general physical standpoint, the existence of domains within a macromolecule implies that a quasi-crystalline structure can be produced within a separate fragment of a macromolecule.

2.3.3. Ternary structures of a gelatin layer

If the intermolecular interaction of two neighboring protein molecules is stronger than the interaction of separate fragments within a structure unit, then linear fibrillar structures can be produced. In the case when the interaction inside a structure is stronger than the intermolecular interaction, globular forms of protein may arise [36,37] (Fig.9).

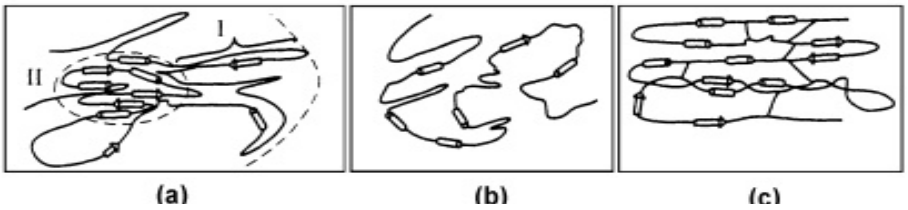


Fig. 9. The ternary structure of a macromolecule. (a) The ternary structure of a macromolecule in the form of a globula,(I) skirt and (II) nucleus of a globule. (b) The ternary structure of a macromolecule in the form of a Gaussian glomerule, (c) The quasi-fibrillar ternary structure of a macromolecule. Formation of the quasi-fibrillar conformation is caused by (1) the tendency of a gelatin macromolecule to return to its native hyperhelical collage state; (2) the presence of thermal fluctuations, which prevent the chain from condensing into the globular conformation; and (3) topological and steric constraints on the conformational state of the considered molecule due to the presence of neighboring molecules.

Both of these ternary hypomolecular structures have a monomolecular character. Therefore, native (natural) proteins are divided into fibrillar and globular ones. Conformational transitions between the ternary hypomolecular structures are reversible. The condition for such transitions is a viscous-flow or dissolved state of proteins. Both of the ternary conformations specified above are characteristic of gelatin. The globular form is preferable in dilute solutions. In strong solutions and gels, the considered conformations coexist, but the fibrillar form is predominant [37]. The fibrillar conformation predominates in thin gelatin films on substrates ensuring a high adhesion of gelatin.

2.3.4. Quaternary structures of a gelatin layer

Formation of coarsely dispersed ternary gelatin structures results in the appearance of boundaries between these structures, and the action of surface forces leads to the aggregation of ternary hypomolecular structures, i.e., formation of quaternary structures (Fig. 10). The forces of surface interaction are of the same nature as the forces of intermolecular interaction. The sizes of protein aggregates range from 1 to 10 μm, which allows us to classify these aggregates as colloidal particles. Ternary and quaternary structures of gelatin determine physical and mechanical, viscosimetrical, and surface properties of gelatin films [38].

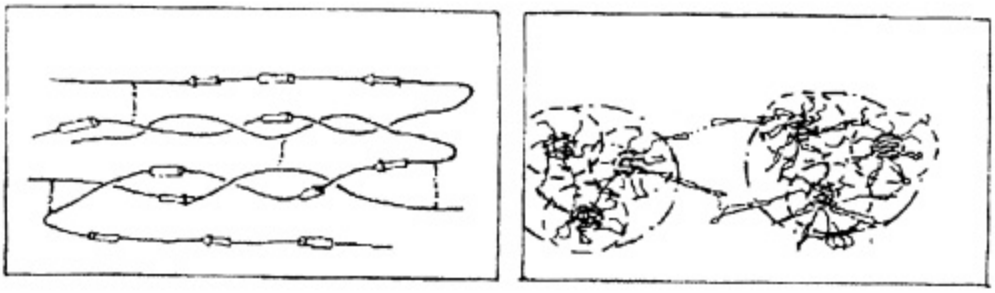


Fig. 10. Quaternary structures representing aggregations of several macromolecules. (a) The globular quaternary structure of an ensemble of macromolecules arises when intermolecular bonds predominate over the external forces. (b) The fibrillar quaternary structure of an ensemble of macromolecules where separate segments of neighboring macromolecules may form a collagen-like hyperhelix.

2.4. Control of the structure of a gelatin layer

Macroscopically, in the preparation of a DG layer, gelatin as a polymer system passes through a sequence of different aggregate states. The initial state in this sequence is a dilute solution of gelatin in water, where macromolecules reside in the state of a Gaussian glomerule, or a globule. In the process of DG-layer preparation, as the solution is poured onto a substrate, the interaction of chain macromolecules gives rise to the formation of gel, which may feature properties of a liquid crystal in the case of rigid-chain molecules or properties of a strong solution with equal volume portions of a solvent and a polymer [37].

As the solvent (water) is evaporated out of the emulsion poured onto a substrate, macromolecules return to the native state, forming a collagen-like triple helical structure. The deformation degree of this structure is determined by conditions of film formation. In the case of gelling, the forces acting from the side of a substrate and conditions of drying lead to the unfolding of macromolecules into linear structures with simultaneous twisting of segments of these structures into helixes. Such a renaturation in the course of gelling has a statistical and local character and occurs through the linking of segments, giving rise, in its turn, to a clearly pronounced short-range order in a gelatin film. A long-range order, which is characteristic of collagen, is not observed in this case [40]. Depending on the thickness of emulsion applied to a substrate, films obtained by molding through gelling on solid substrates feature a planar orientation of their structure elements. Obviously, the state of structure elements in a film depends on the state of these elements in emulsion solution. Specifically, gelatin in a film obtained from solution at a temperature higher than 35 °C has a conformation of a Gaussian glomerule [33, 37, 41] and does not display any features of ordering and planar orientation of structure elements. The degree of adhesion of emulsion to a substrate can be controlled with the use of a gelatin sublayer with a thickness of 0.5-1 μm having a variable degree of hardening or a sublayer of a 5-10% solution of sodium or potassium silicate (liquid glass).

Thus, in synthesizing and pouring DG layers, one can control the structure of a gelatin layer. Below, we describe procedures of such a control.

2.4.1. DG layers with the maximum helicity of the secondary structure

We used a standard technique [42] and water vapor [43] combined with a specific temperature regime to prepare DG layers with the maximum helicity of the secondary structure. An aqueous solution of gelatin with a weight content of dry gelatin from 0.5 to 6% was filtered, degasified, and poured simultaneously with cooling down to 30-35 °C onto a glass substrate heated to the same temperature. The substrate was placed horizontally on a heated thick glass sample. For gelling, the plate poured with solution was kept in a cooler at a temperature of 5-10°C during 4-6 h. The thickness of the DG layer thus prepared mainly depends on the initial concentration of gelatin solution. The DG layer was sensitized in an aqueous solution of ammonium dichromate at a temperature no higher than 20°C during 5-7 min. The concentration of ammonium dichromate should not exceed the initial concentration of gelatin solution. Otherwise, crystal structure may appear in a DG layer, and the intrinsic light scattering coefficient may increase for such a layer.

Preparation of DG layers with the temperature regime specified above ensures gelling with the maximum helicity degree of the secondary structure state. The required level of pre-exposure hardening of a gelatin layer is achieved with an appropriate dose of illumination of the prepared and sensitized DG layer with a UV lamp or sunlight.

2.4.2. DG layers with a globular structure

For the preparation of thin gelatin layers with a globular structure, 0.2-1.0% aqueous solution of gelatin was poured onto a substrate cooled down to 5°C and then evaporated in a vacuum in accordance with the technique described above. For higher (up to 5%) gelatin concentrations, up to 20-30% of isopropyl alcohol was added to gelatin solution to prevent gelling (the Henderson method [39]). Then, such a solution was poured onto a substrate and dried in a vacuum.

For preliminary hardening, a 5% alcohol solution of quinone was added to gelatin solution before evaporation, which made it possible to produce DG layers with a globular structure.

To ensure a high intrinsic photosensitivity with respect to red light, ammonium dichromate (5-100% of the weight of dry gelatin) was introduced into gelatin solution. Upon the addition of ammonium dichromate to gelatin solution, all the procedures were performed under illumination with weak red light.

Self-developing DG layers were prepared in accordance with the technique described in [44] with addition of 90-95% glycerol.

2.5. Experimental results.

After holding the emulsion layer during a day the quasicrystal selfdeveloping dichromated gelatin structure was formed. In order to eliminate the influence of all transition processes, the hologram was recorded 10-12 hours later. We illuminated samples with interference pattern constructed by two plane light waves from the HeNe laser. The spatial frequency of the recorded diffraction grating was hundreds lines/mm. The energy of two beams was 6mW. Diffraction efficiency was measured as the relation of intensity values of diffracted and input beams.

2.5.1. The IR laser annealing

The variable parameters for the annealing IR pulses are the pulse energy, duration, and shape. It should be mentioned that maximal diffraction efficiency obtained in SD DG layers is about 70%. However when we analyzed the effect of different factors on the diffraction efficiency we were working in the range of 5-10% efficiency in order to eliminate the influence of non-linear properties of medium.

The experimental results for IR laser annealing are shown in Fig. 11 for holographic grating of 600 lines/mm recorded in selfdeveloping dichromated gelatin layer of 1mm thickness by radiation of HeNe laser. We analyzed the dependence of diffraction efficiency on the amount of IR laser annealing pulses and full pulses energy (E_{an}) and the best result occurred for six annealing pulses. Figure 11 shows the obtained increase of the diffraction efficiency of hologram (DE_{an} is the diffraction efficiency of SD DG test hologram with IR laser annealing). The best result received at an annealing by six pulses with duration 3 msec at full impulses energy equal to 18-30 J. However, the exact energy level depends on the material thickness, on the concentration of gelatin in emulsion, and on the type and series of gelatin. It should be pointed out that all obtained values of diffraction efficiency for the annealed materials are higher (on average 2-3 times) than they are for the plates not subjected to the annealing. It is visible that the diffraction efficiency curve (Figure 11) has the brightly expressed peak (for annealing energy more than 20 J) at small pulse duration. Further increase of pulse energy leads to considerable diffraction efficiency increasing.

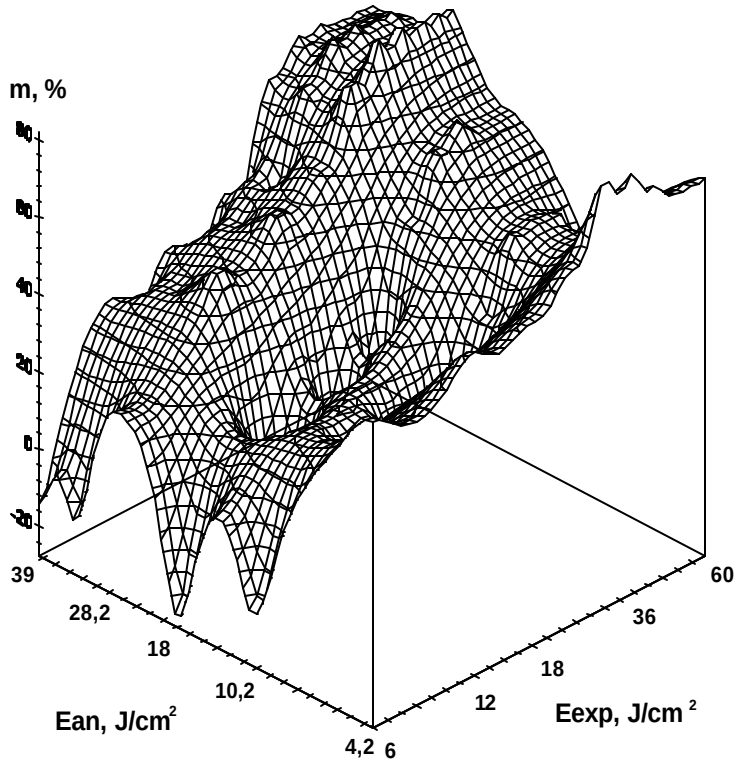


Figure. 11. Diffraction efficiency of holograms recorded in selfdeveloping dichromated gelatin layers with different energy of IR laser annealing pulses with 3 msec duration of six annealing pulses.

The pulse irradiation regime for laser annealing is preferable, because it allows to estimate precise energy of effect on the layer structure. The pulse irradiation is to some extent like sharp system «shaking», and the necessary macromolecules packing is reached by the following relaxation processes in the system.

In our opinion IR electromagnetic field causes impulsive disturbance of water at the level of collective modules while single water molecules and gelatin squirrels do not absorb radiation of 1 μm wavelength [45]. Water quasicrystal net rearrangement conducts the change of electromagnetic field affecting gelatin macromolecules. These macromolecules move under of this field action and change therefore tertiary and quaternary conformation status to achieve an energy minimum in new quasicrystal net. Thus spiral segments do not change, and this means that the SD DG system photosensitive properties do not change too.

In general our experiments showed that the variety of pulse parameters affect on the resulting diffraction efficiency value. The main parameter is, of course, the amount of energy absorbed by the material. However, the pulse duration and its shape (this means the sharpness of fronts) as well as the moment of the annealing relatively the emulsion maturing time are also of importance. It is obvious from the experiments that there exist several solutions to reach the maximal diffraction efficiency by combining the optimal pulse energy, shape, duration and amount of pulses. However that concerns the moment of annealing, multiple experiments showed that the optimum is around 24 hours after emulsion pouring on substrate

2.5.2. The influence of adhesion to substrate on the selfdeveloping dichromated gelatin structure

Experiments showed that SD DG layer separation from glass substrate often occurs causing the diffraction efficiency reduction. This effect is called photoinduced collapse of the emulsion at recording. For elimination of this phenomenon we proposed to utilize an additional gelatin sublayer with the hardness higher than it is for the photosensitive emulsion layer. We investigated what optimal value of the sublayer hardness. The dependence of holographic properties of the SD DG layer on the substrate hardness is shown in Fig. 6. One can see from the Figure 12 that the maximal diffraction efficiency was observed for the sublayer subjected to hardening in ORWO-400 during 4.5 minutes (corresponds to H=4.5).

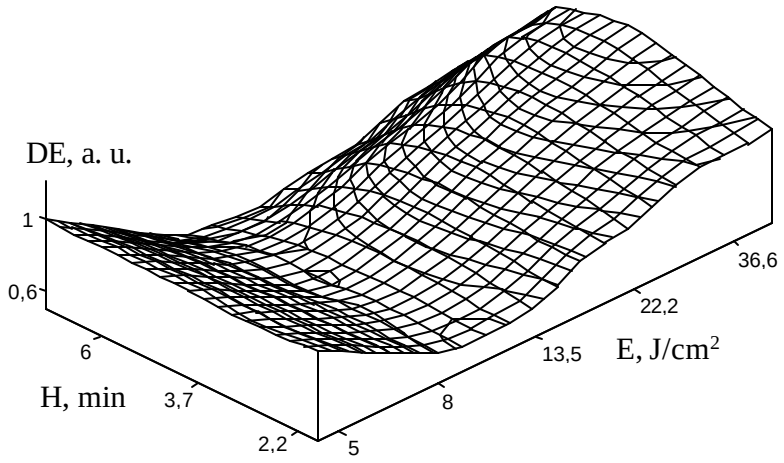


Fig.12. Influence of hardening degree ? of sublayer on the SD DG exposition characteristics.

2.5.3. SD DG emulsions containing high-molecular-weight polymer

We developed the new version of selfdeveloping dichromated gelatin, in which 50 % of glycerol in emulsion was replaced by natural polymer (polysaccharides similar to starch) obtained from plants, its molecular mass is about 20,000. The experiments showed considerable reduction of the layer gelatination time (Figure 13). The formation of quasi-crystal structure occurs faster in this case compared with initial version of SD DG. Obtained holograms have improved storage time.

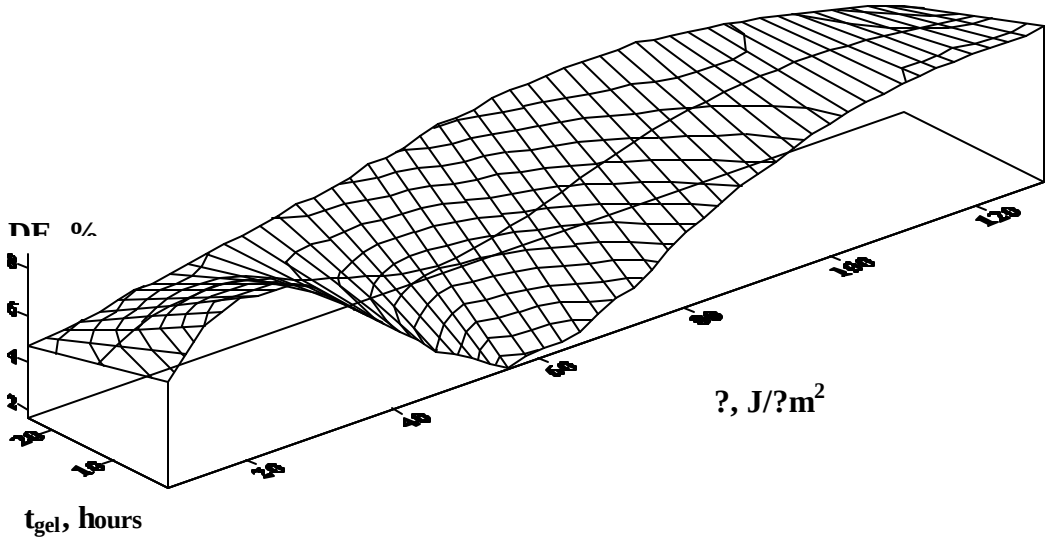
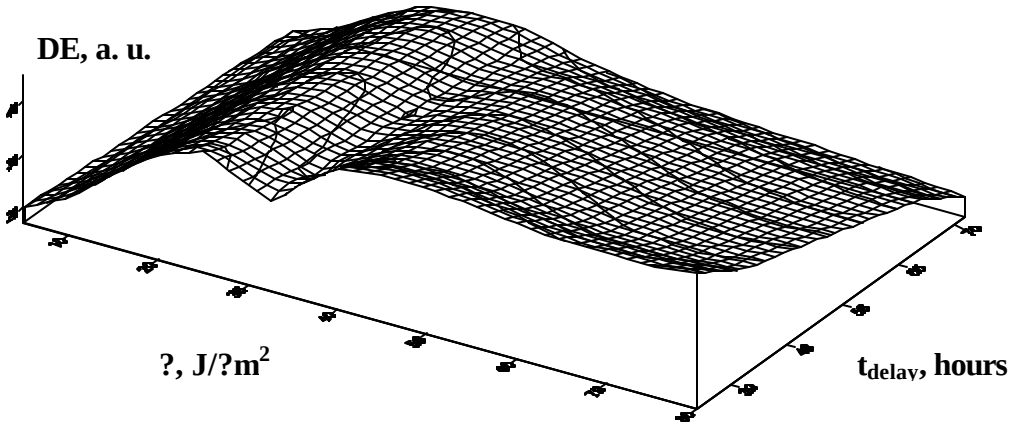


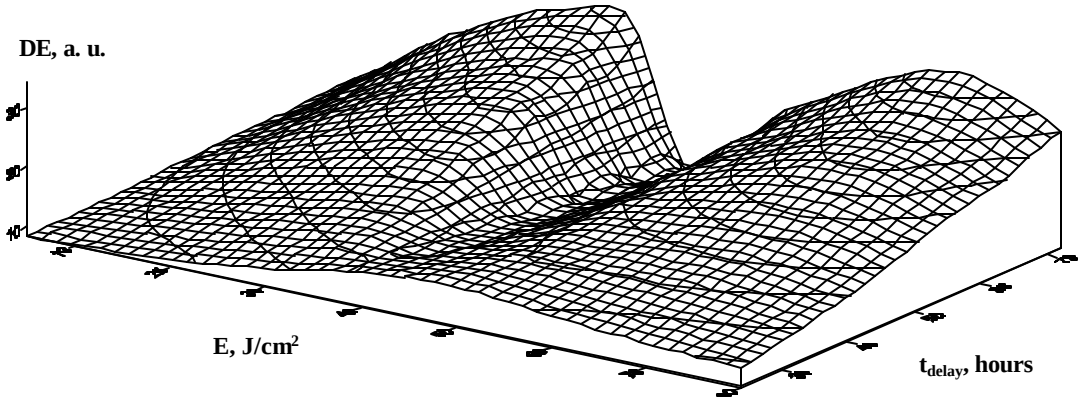
Fig.13. Influence of the gelatination time on the SD DG exposition characteristics for 50% polymer replacement of glycerol.

2.5.4. The SD DG emulsion doped by KCl

We investigated the influence of salt addition to the composition. We used KCl, because it is known that K ions affect the aquacomplex structure. The experimental results are shown in Figures 14, (a) and (b). It is found that KCl essentially improves photosensitivity of the emulsion. The shape of the diffraction efficiency contours changes under the influence of KCl, however the character of this change depends on gelatination temperature schedule.



(a)



(b)

Fig. 14. The hologram diffraction efficiency for SD DG doped by KCl in the gelatination time dependence at temperature 24? ? (a) and at temperature 0^0 ? (b).

7. Conclusions

All goals of the Work plan were successfully achieved. Namely:

- Basing on investigation of photoeffect in colloid systems we developed synthesis of the two types of self-developing material, namely DG layers with the maximum helicity of the secondary structure and DG layers with a globular structure. We proposed different technologies to improve the holographic characteristics (diffraction efficiency, storage time) of selfdeveloping dichromated gelatin material. It was shown that IR laser annealing (series of pulses) before hologram exposure results in increase of diffraction efficiency. In order to overcome the problem of the photosensitive layer separation from the substrate we proposed to use strongly hardened gelatin sublayers. It was shown experimentally the improvement of diffraction efficiency in this case. It was shown that the storage time of hologram can be improved by replacement of part of glycerol by natural polymer with high molecular weight. An addition of salt to the emulsion leads to the increase of the material photosensitivity and to the diffraction efficiency improvement due the influence of ions on water molecules inside the material.
- We considered the mechanism of the optical data recording in DG layers as a set of hierarchical interrelated phase transitions at various levels of gelatin structure, including the intramolecular, molecular, and supermolecular levels.
- The obtained resolution and photosensitivity are the same or above those planned in the project Work plan. For the optimal recipe and development procedure the recording power density for 0,63 μm wavelength was equal 5-6 mW/cm^2. For the spatial frequencies from 300 to 2000 lines per mm and for diffraction efficiency of about 50% the exposing energy was near 45 mJ/cm^2 for 2 mm laminated film thickness. For the spatial frequencies from 2000 to 5000 lines per mm and more (reflection hologram of the mirror) diffraction efficiency of about 30% was achieved at the exposing energy near 100 mJ/cm^2 for 2 mm laminated film thickness.

Materials with the thickness of photosensitive layer of about millimeters can find wide application in development of modern optical information processors, in optical memory systems with multiple page information recording, in fiber communication, etc.

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4. List of published papers and reports with abstracts

1. Laser annealing of colloid recording materials for holography, I.Bogdan, Yu.Vygovsky, Yu.Zagainova, A.Malov, S.Malov, V.Molotsilo, A.Petrov, N.Reinhand, Doklady Akademii Nauk, v.382, #6, pp.764-769 (in Russian, translation available).

ABSTRACT: Selfdeveloping dichromated gelatin (SD DG) is holographic photosensitive medium that possesses the number of unique properties. Being illuminated by interferometric pattern it records the energy distribution, and in such way the gratings with high diffraction efficiency can be obtained. The absence of postexposure processing allows to use it for in-situ experiments. The mechanism of the hologram formation in the material is proposed and the possibilities to control this process by means of the laser annealing are considered. The recorded hologram is the result of conformational changes in the structure of a gelatin system. It is the result of hierarchy of sequential structural gelatin macromolecules modifications. Characteristics of these processes can be effectively controlled at the levels of the primary (the chemical composition of emulsion) and ternary (coil-globule transitions for the entire macromolecule) structures of the SD DG system. We analyzed the influence of IR laser annealing on the gelatination acceleration and resulting diffraction efficiency of layers with thickness more than 1 mm.

2. Recording materials for holography based on dichromated gelatin, A.Malov, Yu.Vygovski, N.Reinhand, I Semenova, Quantum Electronics, submitted in 2001, in press (in Russian, English translation available)

ABSTRACT: Photoinduced chemical reactions and the hierarchical structural and phase transitions in macromolecular architecture of dichromated gelatin is considered. The peculiarities of phase relief formation in DCG during various processing regimes ("wet", vapor, self-developing) are discussed. The role of free and tied water molecules in DCG is analyzed, and the ways to control the process of phase hologram recording are discussed. The advantage of DCG layers consists in the possibility to control the hologram quality via checking the latent image. The main emphasis is made on DCG sensibilization for red spectral range and the technology to obtain very thick (up to 5 mm or more) self-developing DCG layers for volume holograms recording with extremely high selectivity. The possibility to use IR laser annealing, additional adhesion sublayers and electrolytic compounds of emulsion is discussed. The results and perspectives of DCG application in display holography, holographic and speckle interferometry, holographic memory and computer optics, fiber optical communication, for creation of highly selective astronomical filters and solar energy concentrators are considered.

5. List of presentations at conferences and meetings with abstracts

1. Some aspects of atmospheric compensation by means of dynamic holograms.
I.Semenova, S.Dimakov, G.Dreiden. International Conference on Optics for Sensing and Nanotechnology'2001, Yokohama, Japan, June 2001.
Proceedings SPIE, v. 4416, 162-165, 2001.

ABSTRACT: In the present paper we consider an approach to automatically correct aberrations induced by atmosphere in laser communication signals by means of dynamic holograms. The main requirements to a dynamic holographic material are specified. The most appropriate materials and their parameters are listed.

2. Holographic compensation of atmospheric distortions in laser communication systems.
I.Semenova, S.Dimakov, P.Karavaev. International Symposium "Photonics and Applications", November 2001, Singapore. Proceedings SPIE, v. 4596, 2001, pp. 124-130.

ABSTRACT: An approach to compensate atmospheric disturbances in free space laser communication systems by means of dynamic holograms is considered. The possible architectures are discussed. The requirements to dynamic holographic media are specified and candidate materials are listed. Results of a modeling experiment on dynamic phase compensation in BSO crystal are presented.

3. On non-linear correction of atmospheric distortions in laser communication systems.
I.Semenova, S.Dimakov, P.Karavaev. Submitted to APOC 2002 (Asia-Pacific Optical and Wireless Communications), October 2002, Shanghai, China.

ABSTRACT: In the present paper we consider different kinds of dynamic holographic recording media developed to the moment, from the point of view of application in such systems; configuration and characteristics of a correction setup, including those with a moving receiver. The results of laboratory testing of different configurations are discussed.

4. Holographic spectral filters recorded in a new experimental DuPont photopolymer.
I.Semenova, A.Popov, N.Reinhand. International conference Photonics West, San Jose, USA, January 2002. Proceedings SPIE v. 4659, 2002, in press.

ABSTRACT: Holographic spectral filters become popular nowadays in various kinds of wavelength selective devices. The attractive feature of holograms is the possibility to widely vary the final parameters of a filter by choosing the appropriate recording material and recording geometry. However, up to a recent time there was a kind of a gap in attainable spectral selectivity due to the thickness of available materials. The ordinary materials, such as DCG, photopolymers, silver halide etc. are usually 20-30 micrometers thick. The very thick materials, namely porous glasses, PDA and some others start from the thickness of a few hundreds of micrometers. And because of that it was rather difficult to achieve the spectral selectivity of the order from several nanometers up to 20-30 nanometers, which are magnitudes required for many applications. The new experimental holographic photopolymer from DuPont, 50 micrometers thick, is a good candidate to fill in the gap and to obtain filters with the desired selectivity. The paper presents results on the recording of holographic spectral filters in this material.

5. Selfdeveloping dichromated gelatin thick layers: manufacturing and control, A.Malov, N.Reinhand, Yu.Vygovsky, Yu.Zagainova, S.Malov, I.Bogdan, I.Semenova, International conference Photonics West, San Jose, USA, January 2002, Proceedings SPIE, v. 4659, in press.

ABSTRACT: The mechanism of the hologram formation in the selfdeveloping dichromated gelatin (SD DG) material is proposed and the possibilities to control this process are considered. The recorded hologram is the result of conformational changes in the structure of a gelatin system. It is the result of hierarchy of sequential structural gelatin macromolecules modifications. Characteristics of these processes can be effectively controlled at the levels of the primary (the chemical composition of emulsion) and ternary (coil-globule transitions for the entire macromolecule) structures of the SD DG system. We analyzed the influence of IR laser annealing and/or special highly hardened gelatin sublayer on the gelatination acceleration and resulting diffraction efficiency. of layers with thickness more than 1 mm. Salt-doped SD DG layers were experimentally tested. The properties of new version of SD DG emulsion containing organic high-molecular-weight polymer are discussed.

6. The water-blocking buffer gel structure visualization for the real fiber cable and the influence distributed defects to signal loss, I. Bogdan, , B. Levit, D. Lipov, A. Malov, et al. // In: “Asia-Pacific Conference on Fundamental problems of Opto- and Microelectronics and International WorkShop on Optical Beam Transformation”, Vladivostok, Russia: FESTU, (2001). pp. 21 – 26

ABSTRACT: It was shown that the mechanism of the gelatin photosensitivity consists in the sequent hierarchical interrelated phase transitions at various levels of gelatin structure, including intramolecular, molecular, and supermolecular levels. The primary structure is determined by the composition and the sequence of amino acid radicals in a macromolecule of the polypeptide chain. The secondary structure is determined by the configuration and relative spatial arrangement of protein macromolecules. The hypersecondary structure is determined by the aggregation of secondary-structure elements into a single macromolecule, which is manifested, in particular, as the phase state of the globular nucleus. The domain structure is determined by external parameters (the thickness of a layer, the degree of adhesion of the layer to a substrate, etc.) responsible for the formation of separate and relatively weakly bonded globular segments of a macromolecule. The ternary structure is

determined by the conformation of protein helixes in the form of globules. The quaternary structure is determined by dye aggregation of protein fibrils and globules, it is highly sensitive to external conditions.

The understanding of the dichromated gelatin molecular structure allows to create photosensitive material to record multiple elements to be used in various fields of science and industry. The particular application of such elements to fiber communication is discussed.